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ABSTRACT

A computer simulation model for graduate education long-range planning is presented, and the national, state, and institutional forces acting on graduate education are examined. The model was designed to show the causal relationships between three major interdependent academic program elements within a large public university: undergraduate education, graduate education, and research. The Graduate Education Planning Model has been applied to the University of Amherst, both at the campus-wide graduate school level and at the smaller department/school level. The model's emphasis is on the institutional resources (students, staff, and budgets) that are directly reflected in the academic program, where parameters have been selected to allow the model to be applied either to an academic department or to the entire university's combined academic programs. The computer program is written in the FORTRAN language and the model is based on the system dynamics approach. A bibliography is included. (SW)

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A Simulation Model for Graduate-Education Planning in the University

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Robert L. Chew



University of Massachusetts at Amherst

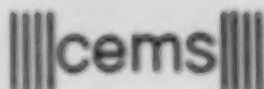
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A SIMULATION MODEL FOR GRADUATE-EDUCATION PLANNING
IN THE UNIVERSITY

by Robert L. Chew
October, 1976

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Center for Educational Management Studies

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I. THE NEED FOR PLANNING IN GRADUATE EDUCATION

Introduction*

The rapid growth of graduate education during the 1960's has declined in some cases, leveled off in others, and, at some universities, has reversed entirely, with major reductions in graduate programs during the 1970's. At a time when resources are strained and pressure for change is being exerted, universities committed to graduate education need assistance in planning and policy-making.

This study will examine the national, state, and institutional forces acting on graduate education, and will then present a computer simulation model that universities can utilize as a long-range planning aid.

The model was designed to show the causal relationships between three major interdependent academic program elements within a large public university: undergraduate education, graduate education and research. In contrast to some of the large-scale and costly resource allocation models that rely on extensive staff and computer resources and that require large data acquisition support systems, this is a simple, highly data-aggregated model based on the system dynamics methodology developed by Jay W. Forrester and his colleagues at the Massachusetts Institute of Technology.¹ The program was written in the widely available FORTRAN language, rather than DYNAMO, which is normally used for system dynamics models.

Based on available budgetary and statistical data, ten-year trends--not intended as projections of specific events--are calculated and put into graphical output form for viewing the financial variables (teaching and research assistantship budgets, faculty salaries budget, administrative overhead budget, and state operating and federal research-funding budgets), and the staff and student variables (teaching and research assistants, faculty, undergraduates, graduate students, and degrees granted). Another variable, the academic program cost per student per year, is calculated to reflect the cost per full-time-equivalent student at any time, based on the total state and research funding required to support the academic program. No attempt was made to identify graduate student costs specifically, because of the inherent relationship of graduate education to the university

*This paper is a condensed version of the author's Doctor of Education dissertation, completed in September 1975 at the University of Massachusetts under the guidance of G. Ernest Anderson Jr., Kenan E. Sahin and Oswald Tippo.

complex.

The Graduate Education Planning Model (GEPN) has been applied to the University of Massachusetts at Amherst, both at the campus-wide graduate school level and at the smaller department/school level. Experiments were made with budgetary cutbacks, changes in the graduate/undergraduate enrollment mix, and student-to-faculty ratios, to demonstrate the model's usefulness in reflecting the results during various policy changes.

Two questions may initially arise in the reader's mind:

1. Why the emphasis on long-range planning, and how can we justify it when resources are already strained by attempts to deal with severe problems in the immediate future?
2. How can computer simulation modeling assist us in planning?

It should be mentioned at the outset that the use of "long-range planning" for the purposes of this study does not imply something like the development of a rigid, five-year plan. The intent here is to ascertain what will likely occur in the long run (up to 10 years) based on present trends and on decisions that may be made now. Accordingly, a response to the first question posed on the need for planning is well phrased by Dresch:

Thus, for the foreseeable future the university will be subject to a confluence of stresses, the most immediate consequence of which is likely to be the unenlightened search for temporary, and ultimately self-defeating, palliatives. The challenge to the university is to adapt positively to a changing environment, where policies must be concerned not with immediate exigencies but with inducing appropriate long-term directions of development.²

Cannack provides us with more reinforcement of the importance of planning:

In actuality, planning is needed to cope with rapid change and to provide ways to deal rationally with the unexpected. It provides ways to deal with the unexpected or undesirable because it establishes a basis for rejecting inappropriate proposals and unreasonable demands. Clark Kerr has said, 'The more one attempts to deal with short-run problems, particularly next year's budget, the more likely one is to encounter resistance to the analysis of alternatives and political commitments that cannot be changed.' As planning horizons move further into the future, people become more objective and more inclined to rational analysis.³

As to the second question, a simulation model provides a tool for managerial experimentation, where the dynamic behavior of an institution under study can be observed and tested under different hypotheses. It is also relevant at this point to quote Sheehan's premises for success in applying simulation modeling to university management:

- a) Much of the value of building a university simulation model is the knowledge of the institution gained during model design, testing and implementation.
- b) The results of modeling should be judged in part on the basis of meaningful management and resource allocation questions that are raised.
- c) A model is never finished--it is continuously modified to match the needs of the users. Flexibility is an important model design criterion.
- d) Spin-off insights should be credited to the model. For example, modeling makes stringent demands on university management information systems. The weaknesses of these systems made apparent by modeling can be corrected to the benefit of all management and operating purposes.
- e) Modeling stimulates an atmosphere in which a logical approach to creative university management is possible.⁴

The present model is intended to reflect the complex interactions in the university of student enrollment, instructional and research staffing, degree production and graduate assistantship support, so that a kind of laboratory for academic policy change will be available to assist decision-makers concerned with problems of resource allocation and quality assessment. The model's emphasis is on the institutional resources (students, staff, and budgets) that are directly reflected in the academic program, where parameters have been selected to allow the model to be applied either to an academic department or to the entire university's combined academic programs. Budgeting considerations in the model do not include those funds associated with student services, physical plant, and capital expenditures. Such a model could be used as an analytical planning tool to augment the academic program review process.

The planning role of the model, and indeed the focus of this study, is perhaps better viewed within the context of decision-making activities in higher education organization and administration:

As one looks at organizations, generally, and institutions

4

of higher education, specifically, three types of decision-making activities are discernible: operations, management, and planning. Operational activities are those focusing primarily on routine, day-to-day detailed transactions within an organization such as payroll, accounting, purchasing, disbursing, and inventory. Management activities are those that provide for the general control of routine operations. Planning activities are directed at the short- and long-range development of program and policy direction of the institution. With the risk of overgeneralizing operational activities affect policy, management activities monitor the implementation of policy, and planning activities establish policy.⁵

Although the operational activities of concern in this study are those dealing with academic programs (student enrollment, student-faculty ratio, teaching assistantship stipends, etc.), rather than those in the preceding examples from financial management, Craven does put the planning function in perspective.

Because simulation is indeed a popular and powerful modeling tool for structuring a system and forecasting the implications of a variety of policy changes, many institutions have developed large-scale, costly models, which, in most cases, do not appear to be completely effective in assisting planners. Here a different--and less costly--approach has been taken to develop a small-scale, deterministic, highly aggregated model. The approach is in general agreement with Bell's observations:

We generally conclude that these models can be of limited use but since creation of a large detailed model is an expensive task, we think it advisable to limit the amount of detail and simply deal with fairly large aggregations of students, staff, and facilities. The reason the models are of limited use is that critical events outside the university influence the flows of students far more than the percentages derived from past flows.⁶

In summary, the principal purpose of this study is to develop and demonstrate a small simulation model for the purpose of assisting academic program planners, primarily in graduate education. An understanding of graduate education within the university is necessary prior to the description and application of the model, and is dealt with in the following section.

Complementarity and Interdependence

One of the primary concerns of policy makers is the increasing cost of research and graduate education, which has given rise to proposals to increase graduate student tuition and to reduce institutional support for graduate student-related research activities. To avoid over-reactions that might damage the basic institutional structure of graduate education, we should try to better understand this complex situation. Dresch recently presented an enlightening economic perspective:

The university's ability to provide graduate training--or rather, the cost at which it can provide this training--depends on the levels of its activity in other dimensions. When undergraduate enrollments or research efforts are relatively low, the cost of additional graduate training may be very high; at high relative levels of these activities, the cost may be low or even negative. In the latter circumstances, the university might find it profitable to pay graduate students to attend.

The cost of any increment in graduate enrollment will depend on:

1. The extent to which graduate faculty requirements can be met by replacing undergraduate faculty with graduate students in undergraduate teaching, and
2. The complementarity between graduate education and research.

With variations over fields, graduate students almost invariably enter as inputs into research, either as substitutes for faculty or for other personnel.⁷

This economic perspective can be grasped by viewing the following simple graphs (Figure 1):

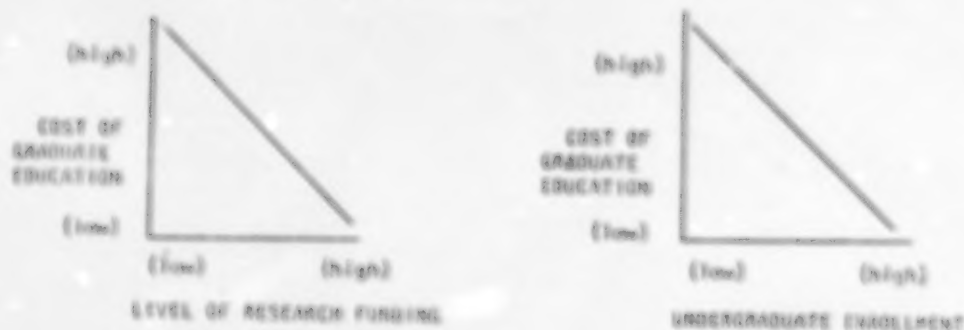


Figure 1. An Economic Perspective on Graduate Education

The student's participation in research and teaching represents part of the graduate education process from which he benefits and for which he is willing to pay by receiving low wages. Thus, many of the apparent costs of graduate education may more legitimately be viewed as the costs of undergraduate education or research. This complementarity can be pictorially represented as follows (Figure 2):

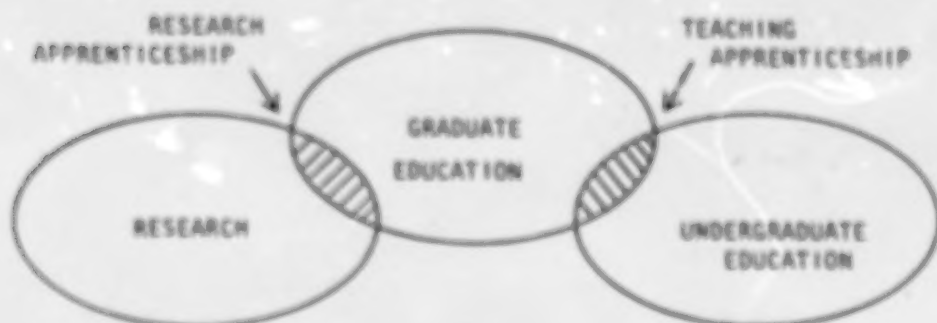


Figure 2. Complementarity and Interdependence of Graduate Education

The intersection of graduate education and research is represented by graduate student research-assistants, whereas the overlapping area of graduate education and undergraduate education is, for the sake of simplicity, represented by teaching assistants as faculty surrogates in the undergraduate teaching process. With the growing flexible and non-traditional forms of graduate education, together with the shift in federal support from basic to more applied research, one might anticipate some reduced emphasis in teaching and research apprenticeship. However, the economic and interdependency models above have several interesting implications, as Dresch points out:

1. The incremental cost of graduate education will probably vary appreciably both over fields and within fields over time.
2. Other things being equal, rapidly rising research efforts or undergraduate enrollments will raise a university's demands for graduate students, thus reducing (or limiting increases in) net graduate tuition.
3. Institutions offering graduate programs will proliferate in periods of rising undergraduate, graduate, or research demands.

4. Contractionary pressures on graduate enrollment in response to declining research activity will be greatest in those institutions whose undergraduate enrollments are growing most slowly and in those most heavily dependent on the relation between graduate education and research as the basis for graduate support.⁸

These implications can be contrasted with a number of problems now facing graduate education:

- a. The cost of financing graduate education continues to rise;
- b. The economic climate in general is not promising for higher education;
- c. Both the current and prospective job market for advanced-degree holders has become less favorable;
- d. General faith in the capacity of science to solve societal problems has declined;
- e. Many people have become skeptical about the role of universities in society;
- f. Earlier projections of enrollment leveling off and declining are now being borne out;
- g. A reduction in federal basic research support for universities has occurred, as well as a significant reduction in federal fellowships and traineeships for graduate students;
- h. A lack of coordinated federal policies toward graduate education, scholarship, and research, is causing continuing financial and programmatic uncertainty that impedes academic planning efforts.

In view of these problems, organized efforts have been made during the past few years on many levels to research and develop principles, procedures, and analytical techniques for use in:

1. The evaluation of quality of individual graduate programs.
2. Determining the costs and benefits of graduate programs.
3. Resource sharing, as a means of reducing the costs of existing programs and assisting in the development of new programs.

4. Information standardization for program comparisons among institutions.
5. Determining and quantifying the joint processes involved with graduate education, particularly basic and applied research, public service obligations of universities, and the impact on undergraduate education (i.e., sharing of the same faculty, involvement of graduate students in undergraduate instruction and new materials in undergraduate curricula, and extensive library, laboratory, and other research facilities available to undergraduates).

2. GRADUATE PROGRAM PLANNING AND REVIEW METHODOLOGY

Cost and Benefit Analysis

Graduate education is intertwined with basic and applied research, and to a growing extent with public service obligations and undergraduate education, through the sharing of faculty and other institutional resources, through graduate student apprenticeships, and through graduate instructional spin-offs into the undergraduate curricula. How does one go about analyzing the costs of these complicated joint processes? The costs of graduate education may be viewed from a number of perspectives, such as the cost to society versus the benefits (i.e., better quality of life), or from the point of view of the student in terms of costs of attendance to complete the degree program and the lost earnings during study. However, we will review attempts to analyze costs (and benefits) only from the institutional perspective.

Start-up costs for a new graduate program should include necessary adjustments for additional faculty, library and building space, and all the institutional supporting resources. Transitional operating costs must be computed each year until the program reaches some maturation, after which the annual operating costs can be projected more accurately. But given the present and projected constraints on graduate education, the emphasis in recent cost analyses is on resource allocation and reviews of existing programs.

As part of its general obligation to assess its resources critically to ensure they are allocated wisely, universities need to review graduate programs in the light of their contribution to the general goals of the university. Also, continuing consideration needs to be given to sharing expensive resources and facilities among groups of universities.

Balderston gives four attributes affecting the cost of a particular graduate program: (a) the scale of the program, (b) the methodologies of scholarship and modes of study specific to that field, (c) the quality aspirations for the program, and (d) the efficiency with which resources are used. He poses three interesting problems for program-cost analysis facing many major universities today:

1. Where are the university's resources now going (i.e., considering the total operating expenditures of the institution in a given year)? What amounts out of that total can be imputed to each program, including a segregated cost rate for each graduate program?
2. What should the cost rate be to provide needed improvements in specified graduate programs (especially, improvements of the sort that money

can buy in the near term)?

3. What costs presently borne would be avoidable if specified programs were dropped, and over what time horizon would expenditure reductions be realizable?⁹

Cost-allocation schemes, such as the WICHE/NCHEMS Resource Requirements Prediction Model, are intended to help answer the first question.¹⁰ This is a deterministic, averaging, cost-accounting computer prediction model that does not seek to optimize university operation; nor does it relate to revenues or evaluate output. The input includes enrollment forecasts, student preferences, staffing patterns, load factors, salary and cost schedules, changes in planning assumptions and instructional programs. The output comprises the resources (personnel, space, and dollars) the institution requires to operate under the simulated conditions.

Other approaches to program costing, essentially based on budget analysis and cost-accounting techniques, have also been used to arrive at cost imputations for graduate programs. Powell and Lamson did an exhaustive review and critique of these methods.¹¹ McCarthy and Deener wrote a useful, brief commentary on the problem, based on the work of Powell and Lamson, concluding that the appropriate unit for consideration of costs and benefits is the graduate degree program (rather than the cost per student per year) and that the basic definitions, procedures, and data are not yet available for cost determination of graduate education.¹² In view of the interdependency of graduate education and undergraduate education and research, it appears infeasible and inappropriate to determine costs specifically for graduate education in the university context. Thus, recognizing the drawbacks of not assessing cost per graduate student by year or by degree program, the model in this study provides an indicator of changing conditions by calculating the annual cost per student, without differentiating between student levels.

As to the second question posed, and in view of the competition for resources, decision makers at higher levels have to ask whether the program is actually apt to improve. They also have to decide whether the financial requests have sufficient priority to be met from resources available for speculation or redistribution.

The third question, on the elimination of programs, is usually answered by demonstrating that immediate reductions of expenditures are small, with the main problem being the reassignment or vacancy of faculty positions.

Direct costs may be derived by examining the elements attributed to the operation of a graduate degree program, including faculty and staff compensation and benefits, contract services, supplies, equipment and travel. Since faculty compensation is normally the largest part of these

direct costs and the most difficult to analyze, the use of "faculty activity analysis" offers an approach to the apportioning of salary costs among teaching (graduate vs. undergraduate), research, administrative, committee, and public service activities. The accuracy and reliability of faculty reports on time spent on these activities is an issue under much discussion and review. Supporting, or indirect, costs of graduate programs include academic support (libraries, computers, laboratories, etc.), student services, institutional administration and physical plant resources, and outside agency support.

Primary output is made up of doctoral and master's degree recipients in the particular field of study, plus those persons who participate in graduate study but do not either complete or aspire to an advanced degree. Secondary output includes research activities and public service. McCarthy and Deener summarized the output in this manner:

Benefits are values perceived in the outputs of graduate education, and these accrue to graduate students, to the public and society, who include both taxpayers and donors, and to the other units in the college or university which offer a graduate degree program. Generally, it is these beneficiaries who provide the funding to the academic institutions and in turn provide for carrying out the graduate degree programs.¹³

In summary, joint processes such as graduate education make for difficulties in cost and benefit analyses. Assumptions, including purpose of the study, time-frame for decisions, and breadth of view, all should be clearly specified when such analyses are undertaken.

The Assessment of Quality

The assessment of quality, although very important in the rapid expansion of programs fueled by federal dollars during the 1960's, is critical in the present period of abrupt slowdown and cutback. One danger is that the major research universities, so heavily dependent on federal support, may be forced to scale down or eliminate some high-quality programs, while other, newer graduate programs, possibly of inferior quality, grow, thereby reducing the overall quality of the nation's graduate education.

Blackburn and Lingenfelter have surveyed the research on quality evaluation of graduate programs, particularly on the assessment of excellence in doctoral programs. They identify two main problems confronting the assessment of excellence in doctoral education: ascertaining the appropriate criteria for excellence, and quantifying the criteria so as to permit comparisons among specific programs.¹⁴

Reputational studies have been designed and carried out to ascertain the criteria for excellence, and to perform comparisons of program quality. These studies, based on peer evaluation or informed judgment, have become widely known for their ratings of graduate programs. The studies are heavily criticized because of the alleged biases of the evaluating panel, the subjective nature of "reputation," the competence of the panel, or the validity of the criteria used in reputational studies. Of all the national studies (Hughes, 1925 and 1934; Keniston, 1959; Cartter, 1966; Roose and Anderson, 1971), the two sponsored by the American Council on Education (ACE) (1966 and 1971) have been methodologically the most sophisticated. These studies have evaluated the scholarly ability of the graduate faculty in a program, using as a criterion "program effectiveness," defined as "The accessibility of faculty and their scholarly competence, curricula, educational and research facilities, the quality of graduate students, and other (relevant) factors."

The National Science Board (1972) identified a number of factors closely associated with quality graduate programs as ranked in the ACE studies:

1. Magnitude of the doctoral program (number of degrees awarded).
2. Amount of federal funding for academic research and development.
3. Non-federal current fund income for educational and general purposes.
4. Baccalaureate origins of graduate fellowship recipients (NSF fellowships).
5. Baccalaureate origins of doctorates.
6. First-year graduate admissions selectivity.
7. Selection of institutions by recipients of graduate fellowships (NSF fellowships).
8. Postdoctoral students in science and engineering.
9. Doctoral awards per faculty member.
10. Doctoral awards per graduate student.
11. Ratio of doctorates to baccalaureate degrees.
12. Compensation of full professors.
13. The proportion of full professors on a faculty.

14. Graduate student/faculty ratios.
15. Departmental size of seven faculty members or more.¹⁵

High scores on these characteristics do not guarantee a quality doctoral education. Another criterion that may be indispensable to excellence is effectiveness in resource utilization (in terms of economies of scale, support, or other factors), given the scarce resources currently available to higher education. Others are client satisfaction, often measured in the form of student and alumni surveys, and employer satisfaction with graduates.

At the institutional level, primary reviews of graduate-program quality are generally performed by a committee of administrators and faculty from other institutions. The review committees generally have access to rudimentary statistical indicators and the indicators of excellence mentioned above; but an important instrument for evaluation at their disposal is wide-range observations and interviews with faculty and students within a program. Carefully corroborated impressions gathered from such a review can help administrators anticipate problems in seemingly strong programs or detect promise in a developing department.

The development of a graduate program planning and review procedure provides a framework for the methodology of graduate program analysis and evaluation, involving cost/benefit analysis and quality assessment through the use of staff resources and analytical tools. The use of simulation modeling is helpful in augmenting the decision maker's long-range perspectives.

Simulation Modeling and the System Dynamics Approach

The use of simulation modeling for planning and resource allocation in higher education seems to have risen in proportion to the increased pressure on higher education for accountability and efficient management. Models of higher education can help explain complex issues that arise in planning and can aid in formulating educational and administrative policies.

Most of the analytical models that have been developed recently have focused on the operating or capital budgets of the institution and not on details of the departmental operation. The larger models have attempted to deal with all the expenditure components of the institution, while a number of specialized models have addressed specific components of the institution in greater depth. For example, several models have been formulated just to forecast student enrollment or faculty distribution. The mathematical complexity of the models varies from simple addition and multiplication

to sophisticated optimization techniques. The functions, underlying theory, methods, subjects, sources of data, uses and operational status of the models developed all vary considerably.

Weathersby and Weinstein have classified the structure and scope of a number of mathematical models into seven major categories: (1) the function or purpose of the model, (2) the theoretical foundation for the particular formulation, (3) the mathematical techniques used, (4) the subject or subjects of the model, (5) the sources of data, (6) the previous and current uses of the model, and (7) the operational status of the model.¹⁶

Schroeder's more broadly based "Survey of Management Science in University Operations" places modeling within the following classifications: (1) Planning, Programming and Budgeting Systems (PPBS), (2) Management Information Systems, (3) Resource Allocation Models, and (4) Mathematical Models.¹⁷

Yet models also may be classified according to their "macro" or "micro" system characteristics, or according to their deterministic or stochastic properties. There are diverse methodological approaches to modeling; however there has been very little emphasis on quality considerations in model development, due to the difficulty of quantifying qualitative aspects.

Johnstone suggests three major problems impeding research in modeling: (1) unavailability of data, (2) efforts to validate models, and (3) which modeling approach is best to use in different circumstances.¹⁸ He suggests that the long-term usefulness of modeling is limited, especially in situations involving rapid change--as is the case with higher education systems today. "Hence model development should be moving from a purely predictive mode of operation to an explanatory/predictive mode."¹⁹ This, however, raises a paradox; that although modeling is best validated under stable conditions, decision-makers are faced with using the unvalidated results of models applied to rapidly changing or unstable systems. Bell has cautioned:

None of the models are capable of predicting and accounting for environmental effects outside the academy. The variables that might have the greatest effect are outside of the model and there is no way to bring them in. With this in mind it is important to design a model of realistic scale that does not exert too much costly energy in making computations at an unreasonable level of accuracy.²⁰

The model proposed here is designed not for comprehensive support efforts, but for long-range planning and experimentation with policy alternatives affecting graduate education. It is simply an analytical tool to augment the decision-making process. The system dynamics approach as developed

by Forrester of M.I.T. has been utilized in formulating the structure of the model.²¹ It provides a framework in which a broad range of quantitative causal hypotheses can be combined into a realistically complex model (representation of theory) and effectively manipulated to study the effects of alternative policies.

Schroeder has put forth a strong argument for the application of system dynamics methodology to social systems:

An essential concept in the study of system dynamics is that it is a method which places primary importance upon correctly representing the structure of the system rather than placing prime importance on accurately reproducing observed real world behavior. Because system dynamics is concerned with "closed-loop," i.e., feedback systems, the modeler is not concerned with factors outside the system which may (and often do) influence behavior, but over which the system has no control. . . . One learns to evaluate the usefulness of a model not in terms of its ability to reproduce the past, but by the degree to which it appears to postulate correctly the forces which operate between the various sectors of the complex system. Once parameters can be defined within a reasonable limit, a great deal of confidence in the model's usefulness in representing the true system, given that the structure is well formulated, is justified. System dynamics is a method which incorporates the same properties as our social systems, and hence is a particularly appropriate tool with which to analyze them."²²

The complex system modeled here, based on system dynamics, is an interlocking structure of feedback loops, involving many kinds of variables that interact in fundamentally nonlinear ways. The feedback loop, central to the theory and techniques of system dynamics, is a closed path connecting in sequence a decision that controls action, the level (state or condition) of the system, and information about the level of the system, the last returning to the decision-making point. See Figure 3 for symbolic representation: the amorphous cloud represents an "infinite source" or "sink" connected to rates that originate outside the system or flow out of the system; the valve symbol suggests the control rate; the rectangle is the level, or accumulator, which gives the state of the system; the circle represents an auxiliary variable, which clarifies how a rate variable depends on a level; a continuous line represents physical flow of a quantity; and the dotted line (either curved or straight) shows information that affects decision-making.

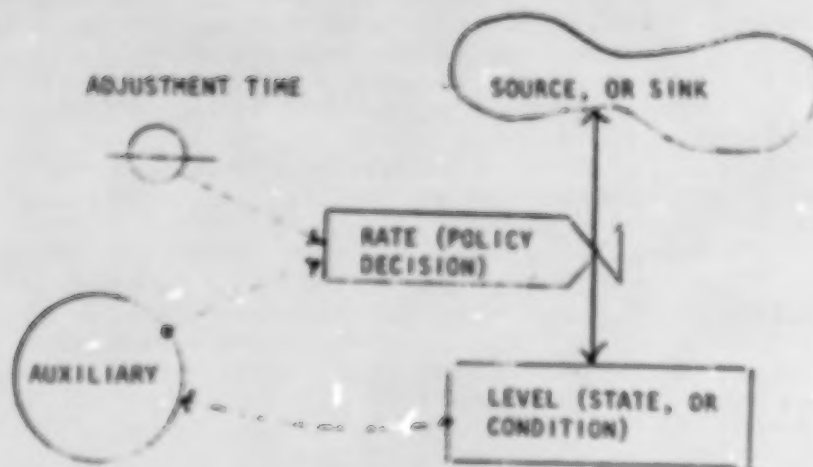


Figure 3. The System Dynamics Feedback Loop

The system dynamics methodology is particularly useful for better understanding of the behavioral characteristics of such complex systems as higher education, as we see from Anderson's recapitulation of some of Forrester's main points on complex systems:

Despite the simplicity of the individual policies in a system, overall system behavior is typically complex, perverse, and counter-intuitive--especially to the untrained intuition which bases its expectations on the well-understood behavior of simple systems. Complex systems are commonly quite insensitive to changes in the numerical values of the great majority of their parameters; to modify a system's behavior significantly, one must either manipulate the very few parameters to which that behavior is sensitive or (usually more fruitfully) change the structure of the system. Interventions undertaken at random are almost certain to be frustrated by one of the following modes of system perversity:

- (1) Complex systems have a strong tendency to resist externally-induced changes by readjusting themselves internally to restore the status quo ante.
- (2) Complex systems tend to start from the point of intervention in the desired or expected direction and then to reverse themselves over the long term, yielding overall results opposite to the intent of the intervention.²³

Anderson's cogent statement on the arguments for system

dynamics (originally called "industrial" dynamics) as opposed to mathematical models is also relevant:

Most mathematical models that have thus far impinged upon education research have been of the statistical-analytical type. Such models manipulate the information contained in statistical data in an attempt to find patterns which will reveal the nature of the systems which generated the data.

Forrester feels that such efforts are doomed to failure because of unrealistic objectives, content and structure.

The content of statistical-analytical models is unrealistic in the sense that the variables that make up such models do not contain the most essential information about the nature of the complex systems being modeled.

Not only is the class of variables irrelevantly restricted, but so is the range of values of variables that do get into the models.

Finally, the output of most statistical-analytical models is relatively hard to translate into policy terms and even harder to translate into the language of the practitioner who must carry out policy.

The structure of statistical-analytical models furthermore fails to reflect that of the complex systems which interest the researcher in education.

In contrast to these negative assertions, we now present Forrester's specific claims concerning the abilities and values of his philosophy, approach, and technique of Industrial Dynamics. These claims include:

- (1) Generality: the modelling technique is based upon the general theory of systems discussed in Forrester's writings. The generality that Forrester ascribes to the theory therefore accrues also to the technique.
- (2) Realism: the proper objectives of Industrial Dynamics models are both valuable and realizable with available resources; the content, structure and behavior of such models faithfully reflect those of the real systems they represent.²⁴

Three of the growing number of applications of system dynamics methodology to the study of higher education are:

1. An examination of the following interrelated dynamic factors of universities: "...increasing

financial pressures, doubts about their relevance, continuing student violence, overcrowding and the chaos of a knowledge explosion...²⁵

2. A highly aggregated model of a university, conceptualized "...as a system of interacting flows of students, faculty, capital assets, information and money...²⁶
3. The development of a model for "...a comprehensive theory of the causal relationships between technical education and prosperity in developing nations...²⁷

These illustrate the applicability of system dynamics to such hard-to-quantify notions as knowledge obsolescence and student frustration operating in a university and influencing research funding and instructional resource decisions. Example 2 deals with more readily quantifiable information, from a global perspective, where student enrollment-demand influences faculty hiring and space requirements over a simulated 50-year period. In contrast, only certain elements that bear directly on the academic program have been selected for this study. Example 3 was cited because it extensively applies system dynamics to the operation of higher education institutions interacting with the larger society.

3. THE GRADUATE EDUCATION PLANNING MODEL (GEPM)

Description of the Model; the System Dynamics Methodology

The purpose of the model is to evaluate how graduate education, undergraduate education and research are affected by long-range changes in policy on: the levels of and support for faculty and for graduate student teaching and research apprenticeship; graduate and undergraduate enrollment levels; and faculty-to-undergraduate and faculty-to-graduate-student ratios.

The model will be used in a highly data-aggregated form, either from the perspective of a campus-wide graduate school where specific disciplines of study are not identified, or on the departmental level, where individual academic programs can be examined. The users of the model will likely be deans, department heads, and committees charged with evaluating graduate education in terms of long-range planning considerations.

The interrelated functions of the model will be treated in a closed system--within the structural and policy concerns of the university. In fact, the model is limited to academic program considerations within the university complex. We know that decisions on physical planning and student services, for example, and decisions of such groups as the state and federal legislatures, will directly or indirectly affect variables of the model, but all such decisions will be treated as exogenous to the model's operation.

The model is fairly simple in concept. However, the detail necessary to make the model at all useful has led to a relatively complex model. In system dynamics terminology it is of the fifth order, which means that five of its variables are formulated as explicit accumulations (or integrations over time). These five level-variables are fed or depleted by thirteen flows, formulated as rate variables in the model equations. The system dynamics approach requires that each rate variable be at any instant a function of: (1) the instantaneous values of the level variables and (2) model parameters that are set at the beginning of a given simulation and that remain constant throughout that simulation. Because some of the rate equations are very complex, or have components that also affect other rates, it has been convenient to separate parts of them into auxiliary equations. In fact, the entire financial sector of the model consists of related auxiliary equations.

There are three general categories of resources under study in the model: (A) students, (B) instructional and research staff, and (C) finances supporting the academic programs. As we see in Figure 4 these categories include six sectors: (1) undergraduate students, (2) graduate

students, (3) graduate teaching assistants, (4) graduate research assistants, (5) faculty, and (6) academic program budget. For simplicity, the notion of full-time-equivalency (FTE), in terms of student, staff, and salaries, has been employed both in data collection and in equation formulation throughout the model.

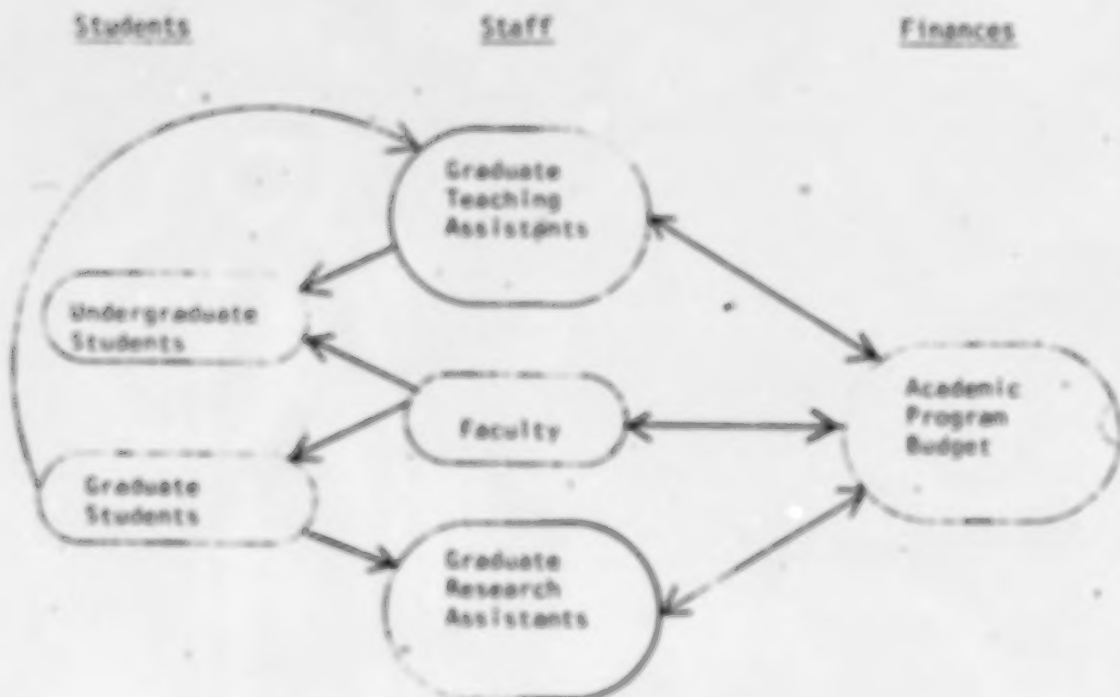


Figure 4. Resource Categories, Sectors, and Causal Interactions

The lines in the diagram above attempt to reflect the direct causal interactions among the sectors where, for example, the number of faculty influences the number of graduate students, based on the instructional capacity of the faculty. In turn, the number of graduate students affects the number of graduate teaching assistants through the user's desired percentage of graduate students employed as teaching assistants, further constrained by the academic program budget allocation for teaching assistantships.

Undergraduate Sector

In the undergraduate sector, illustrated in the system dynamics flow diagram (Figure 5), the student enrollment rate (UGENROL) is influenced by: (1) the undergraduate

enrollment adjustment time in years (UGENROF), (2) the most recent dropouts (UGDROP) and bachelor degree recipients (BACHDEG), (3) the desired total number of undergraduates to be enrolled (DUGENRO), (4) the enrollment level (UGRADES), and (5) the undergraduate instructional capacity (UGICAP). UGICAP is based on: (1) the number of faculty (FACULTY), (2) the number of teaching assistants (TASSIST), (3) the average teaching effectiveness (or capacity) of a teaching assistant as compared to a faculty member (TAFACEF), and (4) the desired (DUGFACR) undergraduate to faculty (plus teaching assistant instructional capacity) ratio. (For the purposes of this simple model it was deemed unnecessary to include any delay function in the flow lines between the rates; this applies to the other sectors also.)

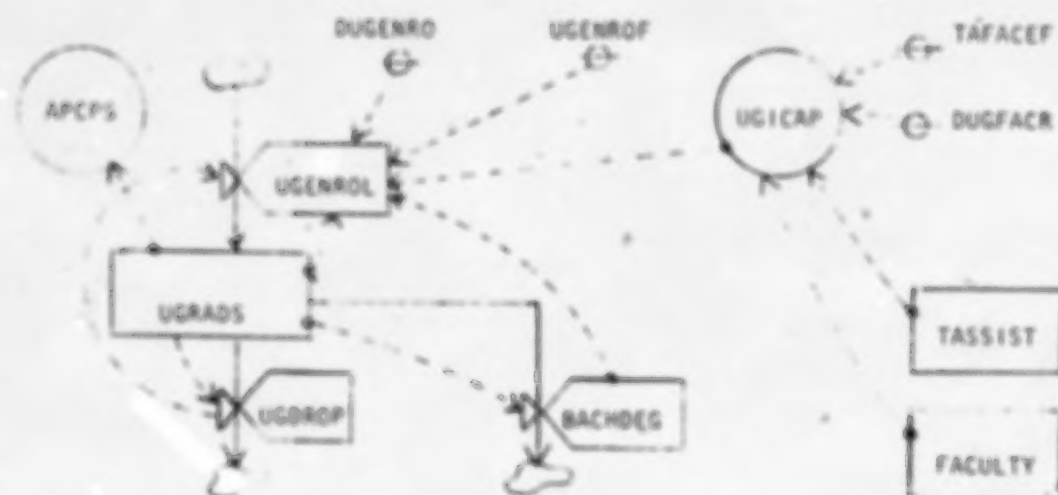


Figure 5. Undergraduate Sector Diagram

UGRADES, the undergraduate enrollment level at any time, is a function of the number of new enrollees (UGENROL) and the departing students, who either drop out (UGDROP) or graduate with the bachelor's degree (BACHDEG). Since the level equation (UGRADES) performs the process of integration, it can be shown in the notation of calculus and differential equations to illustrate the mathematical basis of the method:

$$UGRADES(t) = UGRADES(t_0) + \int_{t_0}^t (UGENROL - UGDROP - BACHDEG) dt$$

where: UGRADES (t)--the value of the level at any time t

UGRADES (t₀)--the initial value of the level at t₀

$\int_{t_0}^t$ --the operator indicating integration or accumulation from time = t_0 until time = t of the difference in flow rates

UGENROL--the flow rate being added

UGDROP, BACHDEG--the flow rates being subtracted

dt--the differential operator representing the small difference in time that multiplies the flow rates

This integration process is carried out in the model through successive executions of the following recursive equation:

$$\text{UGRADS}(t) = \text{UGRADS}(t - dt) + (\text{UGENROL} - \text{UGDROP} - \text{BACHDEG}) dt$$

The dropout rate (UGDROP) is simply a fraction (UGDROFF) of the total number of undergraduate students that leave the university each year by dropping out, failing, or transferring to another institution. The bachelor's degree rate is also a simple fraction (UGBACHF), of the number of undergraduates enrolled that receive the degree each year and leave the system. It should be noted that there is assumed an infinite (or sufficient) source of persons eligible and willing to enroll each year to the extent that the system can handle them (thus the symbolic "cloud" representing an infinite source, leading into UGRADS). Also for the purposes of this model, the number of dropouts and bachelor's degree recipients that are generated over the years through a simulation are not fed back into the model directly; thus the infinite "sink" representations in the diagram. One final link in the undergraduate sector goes from UGRADS (outside this sector) to partially determine the academic program cost²⁸ per student (APCPS), which is also determined by the number of graduate students and the total academic program budget.

The undergraduate instructional capacity (UGICAP), or the maximum number of FTE undergraduates the teaching staff can accommodate, is equal to the desired student-faculty ratio times the FTE teaching staff. The teaching staff consists of both faculty and graduate teaching assistants; in the equation, the number of teaching assistants is multiplied by a fraction (TAFACEF) representing their average effectiveness (or teaching load) as compared to that of the FTE faculty. In DYNAMO language:²⁹

$$A \text{ UGICAP.K} = \text{DUGFACR} * (\text{FACULTY.K} + \text{TAFACEF} * \text{TASSIST.K})$$

For example, if the student-faculty ratio was set at 15, the number of FTE faculty was 100, the number of teaching assistants was 20, and the teaching effectiveness (or load) of a teaching assistant was assumed to be .25 of a faculty member, then the number of undergraduate students able to be "satisfactorily" taught would be:

$$\begin{aligned}\text{UGICAP} &= 15 * (100 + .25 * 20) \\ &= 1575 \text{ undergraduates}\end{aligned}$$

The undergraduate enrollment rate (UGENROL), or number of new enrollees per year, is equal to the minimum of the desired number of undergraduates and the instructional capacity, minus the current level of undergraduates enrolled, divided by the adjustment delay time (set at one year). The most recently calculated number of dropouts and bachelor's degrees are then added to complete this equation, which was formulated in order to allow enrollment level control:

$$\begin{aligned}R \quad \text{UGENROL.KL} &= (\text{MIN}(\text{UGENRO}, \text{UGICAP.K}) - \text{UGRADS.K}) / \text{UGENROF} \\ &+ \text{UGDROP.JK} + \text{BACHDEG.JK}\end{aligned}$$

The undergraduate dropout rate (UGDROP), or number of undergraduates that interrupt their studies toward the bachelor's degree (at the institution modeled), is calculated as a fraction (say, .05) per year of the total undergraduate enrollment level at any time:

$$R \quad \text{UGDROP.KL} = \text{UGDROFF} * \text{UGRADS.K}$$

Similarly, the bachelor's degree rate (BACHDEG), or number of students receiving the bachelor's degree and thus leaving the system, is considered in this model as a fraction (say, .25) per year of the total undergraduate enrollment level:

$$R \quad \text{BACHDEG.KL} = \text{UGBACHF} * \text{UGRADS.K}$$

(In establishing these relationships, care was taken to assume dimensionally correct equations. For example, the above equation is expressed in terms of:

$$\text{students/year} = \text{fraction/year} * \text{students.})$$

The undergraduate enrollment level (UGRADS), or number of FTE undergraduates, is equal to the most recent undergraduate level calculated, plus the incoming rate of new enrollees per year, minus the dropout rate per year, minus the bachelor's degree rate per year; these three rates are then multiplied by the time interval (fraction of a year) used in the simulation calculations.

$$\begin{aligned}L \quad \text{UGRADS.K} &= \text{UGRADS.J} + (\text{UGENROL.JK} - \text{UGDROP.JK} - \text{BACHDEG.JK}) \\ &* \text{TIMEINT}\end{aligned}$$

The relationships above are, of course, crude and highly simplified conceptualizations of the complex undergraduate student flow process, which involves such elements as transfer students, off-campus program students, and short-term dropout

and returning students. But our model was designed to be highly data-aggregated, with equations based on simple, straightforward causal relationships that reflect the real situation fairly well.

A few remarks are now in order to interpret more fully the DYNAMO equations that have been presented thus far.

The "L" equation above is obviously a level type of equation, which was described earlier using calculus notation. Each of the equations is calculated for every increment of the simulation time factor (TIMEINT), which corresponds to "dt" in the calculus notation. (For our model, experimentation has shown that a value of .25 for TIMEINT [$\frac{1}{4}$ year calculation intervals] is a sufficiently small "dt" to produce stability in the computation process itself.) In the level equation, ".K" is a subscript referring to the current value of UGRADS (at time K) while ".J" refers to the most recent past value of UGRADS (at time J). The ".JK" notation (or time interval) on the three rates UGENROL, UGDROP and BACHDEG, refers to the most recent past values of these rates. The "A" equation is an auxiliary type, on which the "R" or rate equation, UGENROL, depends. The parameters without this type of subscript notation (TAFACEP, DUGFACR, DUGENRO, UGENROF, UGDROFF, and UGBACHF) are simple constants that do not change during the simulation, although they may be changed, as may any other parameter or variable of the model, during the initializing process before the simulation begins. The MIN mnemonic refers to an algebraic function that simply selects the minimum value of the two expressions within the parentheses separated by a comma (DUGENRO, UGICAP.K).

The reasoning behind the causal interactions, and the bases for choice of values to initialize and change parameters, will emerge as we build upon these sectors into the complete model and through applications of the model. The remaining five sectors will be described briefly, as they are based on the same principles and use the same notation as in the undergraduate sector.

Graduate Sector

The graduate sector (see Figure 6) consists of the level of graduate student enrollment (GRADS), which changes as graduate students are enrolled (GENROL), and as students drop out (GDROP), receive master's (MASTDEG) and doctoral (DOCTDEG) degrees, and leave the system. The graduate enrollment rate (GENROL) is a function of the desired total enrollment (DGENROL), the graduate enrollment adjustment time (GENROF) that students normally enter each year as either new students or master's degree recipients continuing on toward the doctorate, and the graduate instructional capacity (GICAP), which in turn depends on the desired graduate student-to-faculty ratio (DGFACR) and the total available faculty (FACULTY). The most recent dropout rate

(GDROP), the most recent departing master's and doctoral degree recipients (MASTDEG and DOCTDEG), and the enrollment level (GRADS) also affect the enrollment rate.

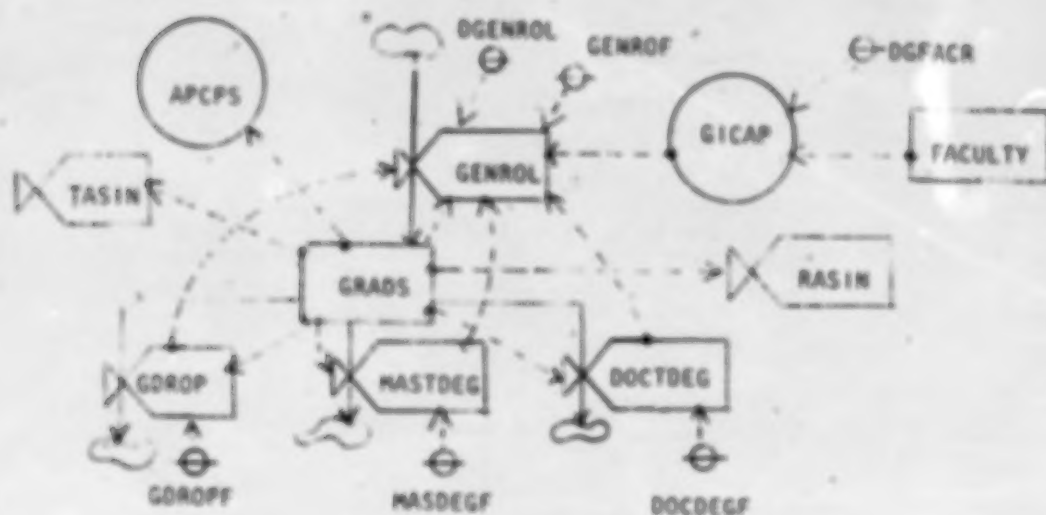


Figure 6. Graduate Student Sector Diagram

The dropout rate (GDROP), the master's degree rate (MASTDEG) and the doctoral degree rate (DOCTDEG), are each simple functions of the number of graduate students enrolled (GRADS) and the annual percentage fractions (GOROPF, MASDEGF, DOCDEGF, respectively) of the total enrollment at any time. The dotted lines leading outside this sector show that GRADS influences: (1) the rate of incoming teaching assistants (TASIN), (2) the academic program cost per student (APCPS), explained in the section on the undergraduate sector and (3) the rate of incoming research assistants (RASIN).

The calculus notation will not be given for the level equation in this or the remaining sectors, as the same underlying mathematics applies. However, each sector description will be followed by its equations described in some detail and then expressed in the DYNAMO language.

The graduate instructional capacity (GICAP), or the maximum number of FTE graduate students the faculty can accommodate, is expressed as being equal to the desired graduate student-to-faculty ratio, times the number of FTE faculty. This elementary relationship to represent instructional capacity obviously must be viewed with caution in applications of this model; furthermore, this relationship can vary considerably among different disciplines of study.

$$A \quad GICAP.K = DGFACR \cdot FACULTY.K$$

The graduate enrollment rate (GENROL), or number of new enrollees per year and master's recipients continuing on toward the doctorate, is equal to the minimum of the desired number of graduate students and the instructional capacity, minus the current level of graduate students enrolled, divided by the adjustment delay time (set at one year). The most recently calculated number of departing students (dropouts and master's and doctoral degree recipients) is also added to complete this equation:

$$R \quad \text{GENROL.KL} = (\text{MIN}(\text{DGENROL}, \text{GICAP.K}) - \text{GRADS.K}) / \text{GENROF} \\ + \text{GDROP.JK} + \text{MASTDEG.JK} + \text{DOCTDEG.JK}$$

The graduate dropout rate (GDROP), or number of graduate students interrupting their degree program, is expressed as a small fraction per year times the number of FTE students:

$$R \quad \text{GDROP.KL} = \text{GDROFF} * \text{GRADS.K}$$

The master's degree departing rate (MASTDEG) is expressed simply as a fraction per year of the number of FTE graduate students:

$$R \quad \text{MASTDEG.KL} = \text{MASDEGF} * \text{GRADS.K}$$

Similarly, the doctoral degree rate (DOCDEG) is a fraction of the number of FTE graduate students:

$$R \quad \text{DOCTDEG.KL} = \text{DOCDEGF} * \text{GRADS.K}$$

Finally, the graduate enrollment level (GRADS) consists of the most recently calculated value of GRADS, plus the above incoming-minus-exiting rates all multiplied by the solution interval (TIMEINT):

$$L \quad \text{GRADS.K} = \text{GRADS.J} + (\text{GENROL.JK} - \text{GDROP.JK} - \text{MASTDEG.JK} \\ - \text{DOCTDEG.JK}) * \text{TIMEINT}$$

Teaching Assistant Sector

The teaching assistant sector (see Figure 7) consists of a level (TASSIST) indicating the number of graduate teaching assistants, which is fed by the incoming teaching assistants (TASIN) and depleted by the outgoing teaching assistants (TASOUT). TASIN is a function of these and of: (1) the teaching assistants' incoming adjustment time (TASINF), (2) the desired ratio of teaching assistants to the number of enrolled graduate students (DTAGRAD), (3) the number of graduate students (GRADS), (4) the academic program budget residual (ACADPBR), (5) the fraction of ACADPBR that is allocated toward teaching assistant stipends (APTABF), and (6) the average teaching assistant stipend (AVGTAS), modified

by a formulation (ATASI) of the annual salary increment.

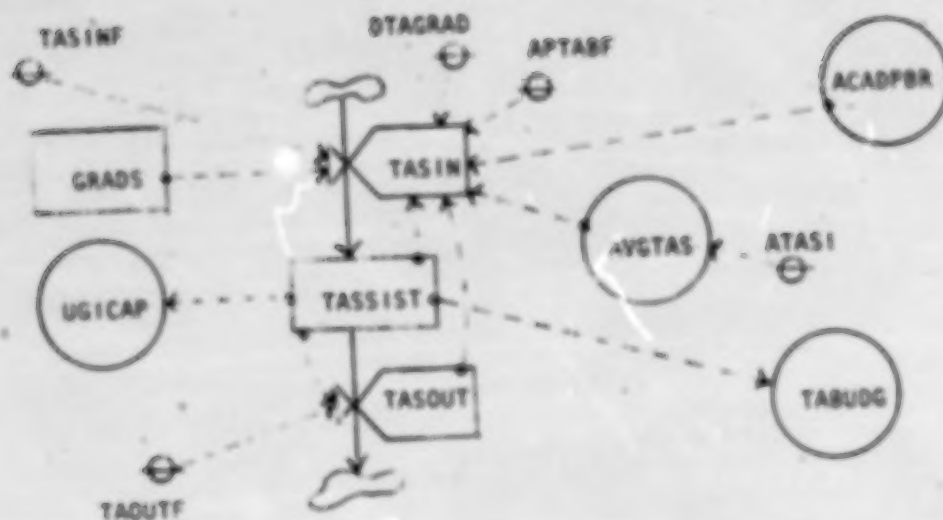


Figure 7. Teaching Assistant Sector Diagram

The TASOUT rate is a fraction (TAOUTF) of the total number of teaching assistants (TASSIST) expected to leave their positions annually. As mentioned in describing the undergraduate sector, TASSIST influences the undergraduate instructional capacity, through teaching assistants employed as faculty surrogates. TASSIST also influences the academic program budget sector in the formulation of the teaching assistant budget (TABUDG).

The teaching assistant incoming rate (TASIN), or number of new assistants employed each academic year, is equal to the minimum of the following two expressions: (1) the desired ratio (a fraction) of teaching assistant positions-to-enrolled graduate students, minus the current number of teaching assistants, divided by the adjustment time of one year, plus the most recently calculated exiting teaching assistants, and (2) the last number of exiting teaching assistants, plus the positive (or negative) number of positions authorized due to budgeting constraints. The calculation of these additional (or fewer) positions is based on the fraction of the academic program budget residual¹⁰ used for providing these teaching assistant stipends, divided by the average stipend.

$$R \quad TASIN.KL = \text{MIN}(((DTAGRAD * GRADS.K - TASSIST.K)/TASINF + TASOUT.JK), (TASOUT.JK + APTABF * ACADPBR.K/AVGTAS.K))$$

The teaching assistant outgoing rate (TASOUT) is a

fraction per year of teaching assistants completing their contracts, times the level of positions:

$$R \quad TASOUT.KL = TAOUTF \cdot TASSIST.K$$

The teaching assistant level (TASSIST), or number of teaching assistants employed at any time, is equal to the most recent calculation of TASSIST, plus the number of entering-minus-exiting assistants multiplied by the solution interval:

$$L \quad TASSIST.K = TASSIST.J + (TASIN.JK - TASOUT.JK) \cdot TIMEINT$$

Research Assistant Sector

This sector (see Figure 8) is based on the same considerations as expressed in the last sector, except that we are dealing here with research rather than teaching apprenticeship. The level of research assistantship can be an influencing factor for inducing research funding into the academic program budget.

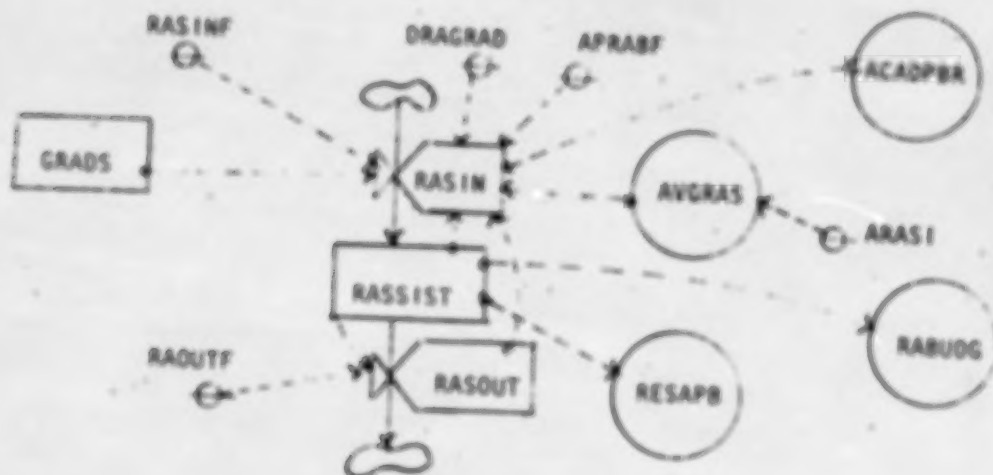


Figure 8. Research Assistant Sector Diagram

This sector's equations are listed without any descriptive text, since they directly parallel those equations in the teaching assistant sector:

$$R \quad RASIN.KL = \text{MIN}(((\text{DRAGRAD} \cdot \text{GRADS.K} - \text{RASSIST.K}) / \text{RASINF} + \text{RASOUT.JK}), (\text{RASOUT.JK} + \text{APRABF} \cdot \text{ACADPBR.K} / \text{AVGRAS.K}))$$

$$R \quad RASOUT.KL = \text{RASOUTF} \cdot \text{RASSIST.K}$$

$$L \quad RASSIST.K = RASSIST.J + (RASIN.JK - RASOUT.JK) * TIMEINT$$

Faculty Sector

The faculty sector, as symbolized in Figure 9, has a form almost identical to that of the previous two sectors. Here again, only the differences will be pointed out. As in the graduate and undergraduate sectors, the faculty level determines the instructional capacity. The diagram also shows the faculty level influences on the academic program budget sector in two auxiliaries: (1) the faculty budget, and (2) the research funding to help support the academic program.

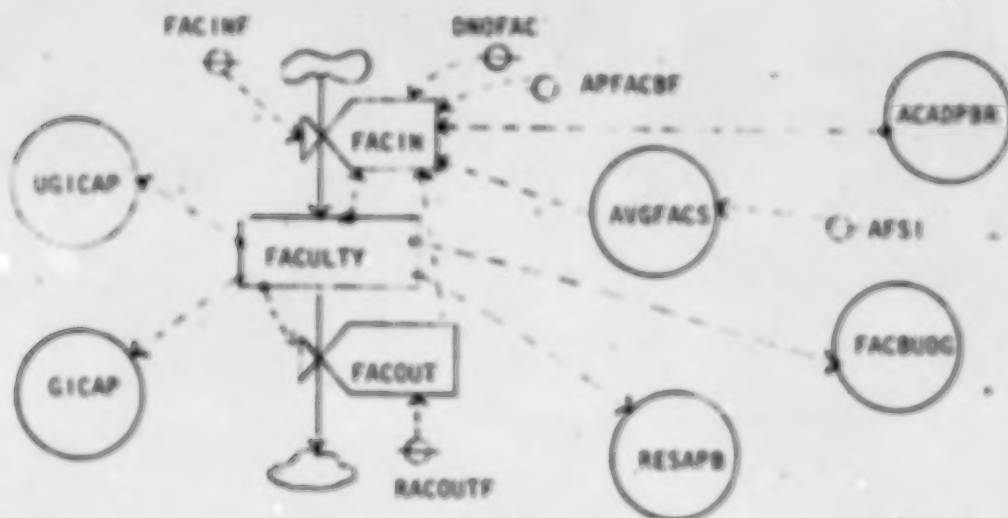


Figure 9. Faculty Sector Diagram

It should be noted that the faculty level (FACULTY) is considered to be the total FTE faculty, including all assistant, associate and full professors. AVGFACS is the average salary of all faculty. As in the research assistant sector, we will list the equations for the faculty sector only in DYNAMO, without other description, since these equations should be understandable to the reader at this point.

$$R \quad FACIN.KL = \text{MIN}(((DNOFAC - FACULTY.K)/FACINF + FACOUT.JK), (FACOUT.JK + APFACBF * ACADPBR.K/AVGFACS.K))$$

$$R \quad FACOUT.KL = FACOUTF * FACULTY.K$$

$$L \quad FACULTY.K = FACULTY.J + (FACIN.JK - FACOUT.JK) * TIMEINT$$

Academic Program Budget Sector

This final sector involves the state funding and non-state (primarily federal, for sponsored research activities) funding for academic program activities of the administrative unit under study. Figure 10 identifies four expenditure budgets: (1) the teaching assistant budget (TABUDG) determined by TASSIST and AVGTAS, identified earlier, (2) the research assistant budget (RABUDG) determined by RASSIST and AVGRAS, (3) the faculty budget (FACBUDG) determined by FACULTY and AVGFACS, and finally, (4) the direct academic program support budget (DSUPBUD) determined by (1), (2), and (3) above in addition to a multiplicative (overhead) factor (DAPSUPF).

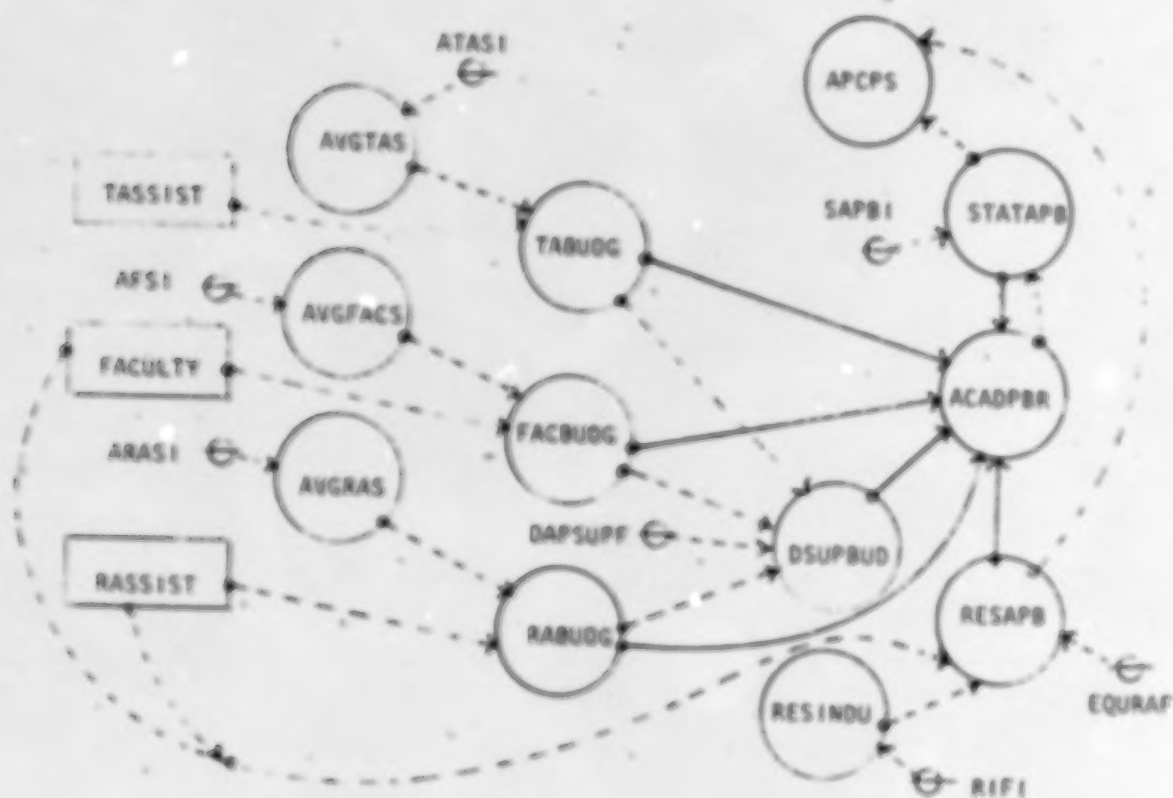


Figure 10. Academic Program Budget Sector Diagram

One of the two incoming budgets, RESAPB, represents the research, or non-state, funding induced by the faculty (FACULTY) and research assistants (RASSIST) to support the academic program. The research factor (RIFI), provides annual increments (which can be positive or negative) to the

research inducement factor (RESINDU). EQUAP is used as a fractional multiplier of RASSIST to represent faculty equivalency for inducing research funding. For example, if EQUAP is set to .25, this means that in aggregate terms, the research assistants are $\frac{1}{4}$ as effective as the faculty in securing research funding.

The other budgetary source, STATAPB, represents the state funding allocated to the academic program. This is influenced by the annual state funding factor (SAPBI), providing either positive or negative annual increments; the most recently calculated budget residual (ACADPBR) also influences the state budget. This residual, ACADPBR, is the surplus or deficit at each calculation of income, minus expenses for the academic program, which constrain the number of incoming teaching and research assistants and faculty (these causal links are shown in the complete diagram in Figure 11). As previously stated, the academic program cost per student (APCPS) at any time is the result of dividing the total number of FTE students (GRADS plus UGRADS) into the total academic program budget (STATAPB plus RESAPB).

The equations of this sector are all of DYNAMO type "auxiliary." The average teaching assistant salary (AVGTAS) per year is equal to the last calculated salary per year plus the average annual increment based on the solution interval. (Note the use of the AVGTAS.J notation, rather than the ".K" notation normally used on the right side of an auxiliary equation in DYNAMO. The purpose of this is to avoid compounding annual increments during fractional year solution interval calculations in our FORTRAN model. This same note applies to the AVGRAS, AVGFACS, STATAPB, and RESINDU equations below, which are all dependent on annual increments.)

$$A \quad AVGTAS.K = AVGTAS.J + ATASI$$

The teaching assistant budget (TABUDG), or funding per year necessary to support all the teaching assistantships, is equal to the average stipend per year times the number of FTE teaching assistants:

$$A \quad TABUDG.K = AVGTAS.J * TASSIST.K$$

Similar equations for research assistants (AVGRAS and RABUDG) and faculty (AVGFACS and FACBUDG) are listed below:

$$A \quad AVGRAS.K = AVGRAS.J + ARASI$$

$$A \quad RABUDG.K = AVGRAS.K * RASSIST.K$$

$$A \quad AVGFACS.K = AVGFACS.J + AFSI$$

$$A \quad FACBUDG.K = AVGFACS.K * FACULTY.K$$

The direct support budget (DSUPBUD), or funding per year for administrative and other expenses directly associated with the academic program, is calculated by multiplying a constant factor by the previous three staff budgets:

$$A \quad DSUPBUD.K = DAPSUPF * (TABUDG.K + RABUDG.K + FACBUDG.K)$$

The state academic program budget (STATAPB), or the state funding requested per year to directly support the academic program, is equal to the last calculated value of STATAPB plus the annual increment (based on the solution interval, to avoid compounding) minus the last calculated academic program budget residual.

$$A \quad STATAPB.K = STATAPB.J + SAPBI - ACADPBR.J$$

The research inducement factor (RESINDU) is the calculated average amount of research funding brought in annually per FTE faculty member equivalent:

$$A \quad RESINDU.K = RESINDU.J + RIFI$$

The research academic program budget (RESAPB) is equal to the RESINDU factor times the faculty equivalency for attracting research funds. (EQURAF * RASSIST was explained earlier with this sector's diagram.) This relationship may be highly questionable when applied to a small department with research grants in the hands of very few faculty members.

$$A \quad RESAPB.K = RESINDU.K * (FACULTY.K + EQURAF * RASSIST.K)$$

The academic program budget residual (ACADPBR) is, as explained earlier, the resulting positive or negative value, at each solution interval, of the incoming funds minus the expenditures. The values calculated for ACADPBR are normally well below one percent of the corresponding values for the total academic program budget (STATAPB + RESAPB).

$$A \quad ACADPBR.K = STATAPB.K + RESAPB.K - TABUDG.K - RABUDG.K - FACBUDG.K - DSUPBUD.K$$

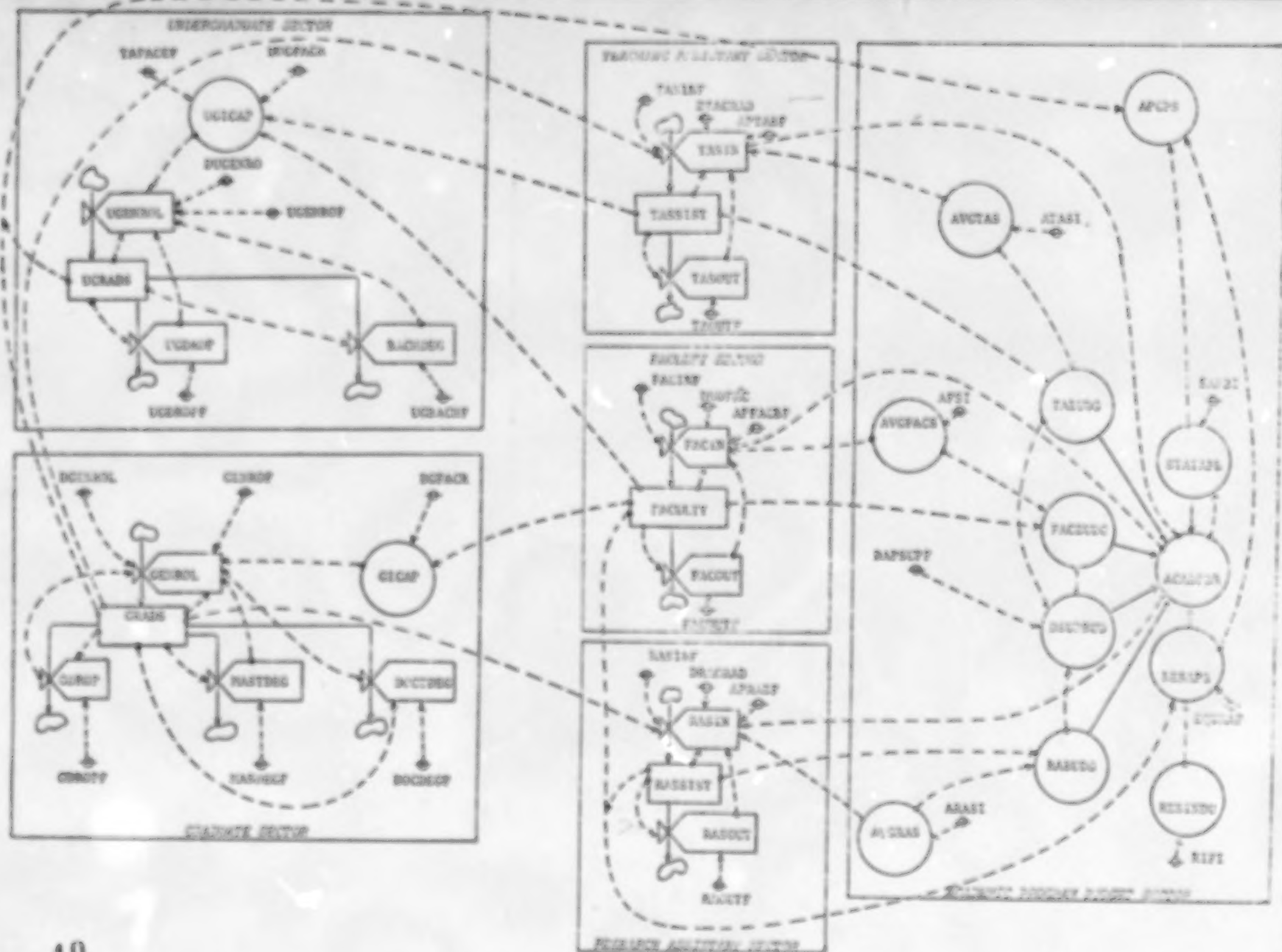
In the final equation the average academic program cost per student is calculated as a marginal indicator of student cost variation over time.

$$A \quad APCPS.K = (STATAPB.K + RESAPB.K) / (GRADS.K + UGRADS.K)$$

Model Overview and FORTRAN Program Formulation

The complete flow diagram of GEPM is displayed on the next page in Figure 11. The main purpose here is to provide the overall model structure and a means of tracing all the

Figure 11. GCM: Complete Flowchart of Causal Interactions



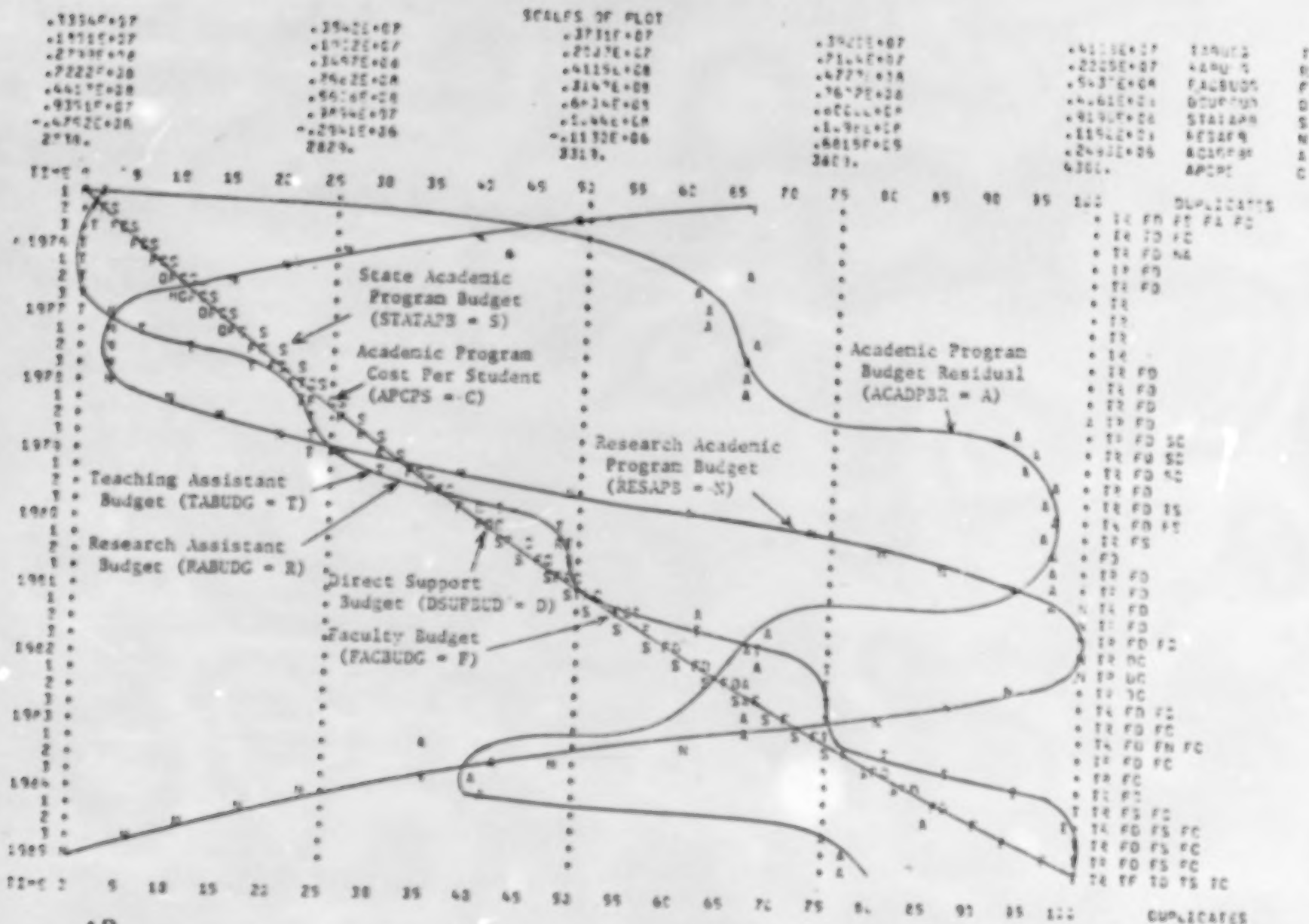
causal paths.

As stated earlier, the model was written in FORTRAN; this was done because (1) the most appropriate language for system dynamics models, DYNAMO, would have been accessible to the author only at considerable expense in terms of time and money, since the nearest computer center with DYNAMO available during the period of this research was at the Massachusetts Institute of Technology (some 90 miles away), (2) although DYNAMO can be used in a time-sharing terminal, it still was not selected for this model because of the normal problems associated with using another institution's computer center from a distance, as well as the fact that GEPM will probably be used mostly in the batch mode, (3) the author has written many programs in FORTRAN and has much more familiarity with this language, and finally (4) the academic computer center at the University of Massachusetts is extremely convenient for the purpose of this study; quick simulation runs and program changes can readily be made as the model naturally evolves, depending on new insights and user demands.

There are, as might be expected, a number of handicaps in using FORTRAN rather than DYNAMO for system dynamics models, since all of the DYNAMO facilities for input and output, the various delay, table, and smoothing functions, and the equation error-checking features, must be either translated somehow into FORTRAN or not used in the model. Two major advantages of FORTRAN, however, are: (1) the widespread use of the FORTRAN language (in contrast to DYNAMO), allowing the model to be used at any university, and (2) the FORTRAN language's being usually less expensive than DYNAMO in terms of computer time costs. Two examples of the computer graphical output (with the curves annotated for greater legibility) are presented on the next pages (Figures 12 and 13). Figure 12 shows the model's financial variables changing over a 10-year period, and Figure 13 illustrates the evolving staff and student factors over the same period of time.

This simulation model continues to evolve (as most models do) from its present state as more experience is gained in using it.

Figure 12. Graduate School Run 1 (Financial Factors)



4. MODEL EVALUATION AND CONCLUSIONS

Evaluation of the Model

In validating the model, the approaches of "first-time" models, posed by Emshoff and Sisson,³¹ have been used to some extent. These approaches are: internal validity, face validity, variable-parameter validity, hypothesis validity, and event or time-series validity. The internal validity--the interrelationships within the model--is an accurate reflection of those aspects of the real system that were deemed relevant. Essentially, validation has consisted of hand calculations made to ensure that results of the simulation model were indeed consistent with expected results, and the presentation of the model and its results in seminars and to individual faculty and administrators for their criticism. A limited amount of "sensitivity analysis" of the model has been performed to date, through parameter value changes and observation of results. The alteration of some parameters produced little change under experimentation; other start-up conditions resulted in significant changes. A general cautionary note from Emshoff and Sisson is pertinent:

When an analyst produces a new simulation model all that can be hoped for is a test of reasonableness and an act of faith that its use will improve decisions. Obviously, in these circumstances it is unlikely that the model will be used for decision making. The simulator may well be used for qualitative or quantitative decision aiding, since in this use the decision maker is not counting on the model alone. He may use other evidence to confirm or revise the model results.³²

Although the causal relationships structured in the present model are based on realistic observations of information from the University of Massachusetts, and are substantiated by other studies noted earlier (as opposed to simply the product of the author's trained perceptions and bias), it is almost impossible to validate such a model in the classical sense. Models--system dynamics models in particular--should be evaluated according to their clarity of structure and their presentation of time-varying results. Indeed, Forrester notes that: "Model validity is a relative matter. The usefulness of a mathematical simulation model should be judged in comparison with the mental image or other abstract model which would be used instead."³³

The model presented differs significantly from most of the large-scale models (i.e., RRPM), in that it is simple and inexpensive to use, does not require an extensive data support system, is longer-range in focus, and is conceptually

on a higher aggregated structural level. GEPM might be useful in a companion role to these large-scale models, to serve both as a check on their results and as a guide to their applications.

As of this writing, the use of the model has only just begun. GEPM, even in its present elementary stage, will provide a useful and insightful testing device for some critical decisions being faced--on enrollment policies, resource allocations, and academic program development. For example, experimentation can be done on budgetary cutbacks, changes in the graduate/undergraduate enrollment mix, and changes in salary increments should faculty unionization occur.

Some limitations of the model should be made clear at this point:

1. The accuracy of the results produced is a function of:
 - a) the author's understanding of the system under study, and his ability to construct and apply the model,
 - b) the experience of the user (in terms of both understanding the operation of an academic institution, and the familiarity with the model's assumptions and structural equations),
 - c) the extent of detail and number of causal relationships reflected in the model. Since the model operates in a highly data-aggregated form, its results must be viewed as trends, and not as accurate projections over time.
2. Only elements directly related to academic programs in the institution are built into the model. Other major influences, both from within and outside the institution's operation, certainly affect academic program considerations. But one of the major assumptions in constructing a closed system was that there would be no control over these exogenous events; thus the exclusion of outside considerations was a predetermined limitation of the model. Obviously, when experimenting with the model and viewing results, other parts of the university and the larger social and economic environment must be carefully considered.
3. To the extent that sufficiently useful data for the model is either unavailable or is unvalidated as to its accuracy, this becomes an obvious limitation in experimenting with the model.

4. The smaller the academic unit being modeled, the more caution should be exercised in applying the model, because it was designed to project trends based on a high level of data aggregation.

Proposed Extensions and Applications of the Model

The model in its present form is deterministic, i.e., it has no stochastic, or random, elements. Although random fluctuations do exist in the system (academic program operation) under study, these random characteristics were ignored in the interest of simplifying the model. As the user gains confidence in the model, certain elements may be more realistically treated through the introduction of randomness. These functions could be developed in the FORTRAN language to extend GEPM, but any real expansion of the model from its present simple form should be done by converting GEPM to the DYNAMO language, through which the methodology of system dynamics can be much more effectively applied.

In the future, GEPM will surely take on additional refinements, will be embellished for more accuracy and will include important structural relationships not yet considered. Many of the program proposals being made in current graduate program reviews may not be able to be tested with the present model; for example, what increase in program quality would result from a proposed increase in academic program funding? Other possible extensions and applications could include studies of:

1. A decrease in the present required number of faculty and teaching assistants, and changes in their mix, due to greater use of instructional aids, such as televised lectures and computer-aided instruction;
2. An increase in the faculty required if a campus becomes primarily a graduate and upper undergraduate "flagship" institution within its university system;
3. A decrease in faculty salaries at urban universities if the choice were made to use a higher percentage of available part-time faculty; also in the urban setting, studies on the utilization of fewer research assistants due to apprenticeship training being available in nearby industry;
4. A shift to a larger percentage of part-time, older undergraduates, assuming an eventual decrease in the 18-21 year-old population, as well as the demand for more part-time graduate study as more

persons hold the bachelor's degree and as professions and careers change;

5. The use of more or less of the academic program budget for administrative direct support functions;
6. Physical space requirements for instructional and research usage in view of the accountability pressures for efficiency in operation and the soaring cost of heating buildings.

Due to more local and regional sharing of institutional resources (including faculty, libraries, computers, laboratories, classrooms, students, administrators), changes could be reflected in the parameters or structure of the model. In fact, GEPM could very well produce a number of offspring, or more program- or structural-specific models, as it matures. With the apparent growth of non-traditional forms of graduate and undergraduate education, both on and off campus, the model may require a very different structure. Time will tell whether the batch or the time-sharing mode (or a combination of both) of model operation is preferable.

The GEPM is a useful analytical tool for assisting the long-range planning process in graduate education administration. While many universities are undertaking major planning and review projects in these constrained economic times, low-cost planning tools such as this could be a welcome source of assistance to faculty committees and deans considering ways to adapt to a changing economic and academic environment.

NOTES

- 1
"System dynamics refers to the methodology developed over the past decade by J. Forrester and others at M.I.T. for representing time-varying causal interactions of complex industrial and social organizations through computer simulation models. The simulation models are used to test alternative management policies, and aim to demonstrate the characteristic behavior of a system operation rather than to predict specific events.
- 2
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- 3
Elwin F. Cammack, "Long-Range Planning," Institutional Research in the University, Paul L. Dressel and Associates, (San Francisco: Jossey-Bass, Inc., 1971), p. 254.
- 4
Bernard S. Sheehan and Marvin G. Michaels, Experience with Planning Models in the University Budgeting Process, Report No. 90, Office of Institutional Research (Alberta, Canada: University of Calgary, February 1973), pp. 9-10.
- 5
Eugene C. Craven, "Information Decision Systems in Higher Education: A Conceptual Framework," Journal of Higher Education, Vol. XLVI, No. 2 (Ohio State University Press, April 1975), p. 128.
- 6
Colin Bell, "Can Mathematical Models Contribute to Efficiency in Higher Education?" Papers on Efficiency in the Management of Higher Education, Carnegie Commission Report (Berkeley, California: 1972), p. 44.
- 7
Stephen P. Dresch, An Economic Perspective on the Evolution of Graduate Education, National Board on Graduate Education, Technical Report No. 1 (Washington, D.C.: March 1974), pp. 28-29.
- 8
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- 9
Frederick E. Balderston, "Difficulties in Cost Analysis of Graduate Education," a supplement in Federal Policy Alternatives Toward Graduate Education, Report No. 3 (Washington, D.C.: January 1974), p. 94.

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John H. Powel Jr. and Robert D. Lamson, Elements Related to the Determination of Costs and Benefits of Graduate Education, Council of Graduate Schools (Washington, D.C.: March 1972).
- 12
Joseph L. McCarthy and David R. Deener, The Costs and Benefits of Graduate Education: A Commentary with Recommendations, Council of Graduate Schools (Washington, D.C.: March 1972).
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Ibid., p. 41.
- 14
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- 15
National Science Board, The Role of Engineers and Scientists in the National Policy for Technology (Washington, D.C.: 1972).
- 16
George B. Weathersby and Milton C. Weinstein, "A Structural Comparison of Analytical Models for University Planning," Ford Research Program in University Administration, Paper P-12 (University of California, Berkeley, 1970).
- 17
Roger G. Schroeder, "A Survey of Management Science in University Operations," Management Science, Vol. 19, No. 8 (April 1973), p. 895.
- 18
James N. Johnstone, "Mathematical Models Developed for Use in Educational Planning: A Review," Review of Educational Research, Spring 1974, Vol. 44, No. 2 (Washington, D.C.), pp. 193-4.
- 19
Ibid., p. 195.
- 20
Bell, "Can Mathematical Models Contribute to Efficiency in Higher Education?" p. 59.

- 21 Jay W. Forrester, Principles of Systems, Wright-Allen Press, Inc. (Cambridge, Massachusetts: 1968).
- 22 Walter W. Schroeder III, "System Dynamics: A Unique Tool for Analysing Data-Deficient Social Systems," IEEE Transactions on Systems, Man, and Cybernetics, Vol. SMC-2, No. 2 (April, 1972), p. 218. [Professor K. Sahin has pointed out to me that, although system dynamics is indeed an attractive and powerful simulation methodology, Schroeder's points are all disputable. He notes some limitations of system dynamics: (1) not much emphasis on historical trends, which play an important part in influencing decision-making, (2) discrete events in reality, but simulated by a continuous method, and (3) not much optimization, which in reality plays an important role in decision-making.]
- 23 Richard Bryan Anderson, "Technical Education for National Prosperity: Industrial Dynamics Applied to the Clarification of an Educational Controversy," Doctor of Education Thesis (Harvard University, 1971), pp. 163-164. (Anderson cites Forrester: Industrial Dynamics, M.I.T. Press, 1961, and Urban Dynamics, M.I.T. Press, 1969).
- 24 Ibid., pp. 165-173, (Again Anderson draws heavily from Forrester's Industrial Dynamics).
- 25 Willard R. Fey and John E. Knight, "The Dynamics of Educational Institutions," Paper presented at Summer Computer Simulation Conference (Boston, Massachusetts, July 19-21, 1971), p. 1.
- 26 Robert K. Thompson, "Higher Education Administration: An Operating System Study Utilizing a Dynamic Simulation Model," in Albert N. Schrieber, Corporate Simulation Models, University of Washington (Seattle: 1970), p. 480.
- 27 Anderson, "Technical Education," p. xiv.
- 28 There is no attempt in the model to ascertain the cost per graduate student, only to calculate the cost per student, i.e., the total full-time-equivalent graduate and undergraduate students divided into the total academic program budget, over varying conditions during the simulation.
- 29 Refer to the DYNAMO II User's Manual (by Alexander L. Pugh III, M.I.T. Press, Cambridge, Massachusetts, 1973) for a description of the DYNAMO language.

30

This residual is the resulting positive or negative value of subtracting the academic program budget expenses from the state and research funds that constitute the academic program budget.

31

James R. Emshoff and Roger L. Sission, Design and Use of Computer Simulation Models (New York: The Macmillan Company, 1970), pp. 204-5.

32

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33

Forrester, Principles of Systems, p. 3-4.

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